MOVEMENT VARIABILITY IN THE FRONTCRAWL AND BREASTSTROKE SWIMMING STARTS

by

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2. Abstract

The purpose of this study was to quantify biological variability of linear and angular kinematics in breaststroke and frontcrawl starts, when using the track start technique. Four male and six female swimmers aged 18 – 21 years old (mass: 70.3 kg ± 3.9; height: 167.1 cm ± 9.5) with a minimum of five years' competitive experience performed ten breaststroke and ten frontcrawl starts. One 120 Hz camera recorded block and flight phases for subsequent two dimensional full body manual digitisation, using Quintic software. One 60 Hz camera captured temporal data of each trial. One underwater 50 Hz camera captured the underwater phase from entry in the sagittal plane. Biological coefficient of variation (BCV%) was calculated by extracting technical error (SEM%) from the coefficient of variation (CV%). A series of paired t-tests were used to compare BCV% of each start parameter between strokes using SPSS version 22.0. BCV% of start parameters and task outcome (time to 15 m were compared). There was no significant difference in BCV% between start parameters of the breaststroke and frontcrawl starts, despite BCV% being lower in the majority of frontcrawl parameters. Variability in task outcome was considerably lower than linear and angular kinematic parameters of the start, supporting the dynamic systems theory. Whilst variability does exist in start parameters, the task constraint of the stroke swam does not produce significant differences in biological variation of key start parameters.

3. Declaration

No portion of the work referred to in this Research Project has been submitted in support of an application for another degree or qualification of this, or any other University or institute of learning.

The project was supervised by a member of academic staff, but is essentially the work of the author.

Signed …………Jessica Smith………………….

Date ……………………21/09/2016……………………………

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Chapter 1

7. Introduction

In competitive swimming, up to 30% of race time can be attributed to the start (Lyttle & Benjanuvantra, 2005). The start is defined as the time from the start signal to the head reaching 15 m (Tor, Pease, & Ball, 2015). It includes block, flight and underwater phases (Maglischo, 2003), with the block and flight techniques consistent regardless of stroke. In accordance with FINA rules, race stroke defines the underwater technique, therefore, different techniques are used during the breaststroke and frontcrawl underwater phases (Appendix 1.1). Components of the race start have been widely researched (Barlow, Halaki, Stuelcken, Greene, & Sinclair, 2014) due to technique and equipment development. The new start block, introduced in 2011, created in a shift in popularity from the grab start to the kick start technique. Following this, Tor et al. (2015) identified the critical parameters of start performance (Figure 1).

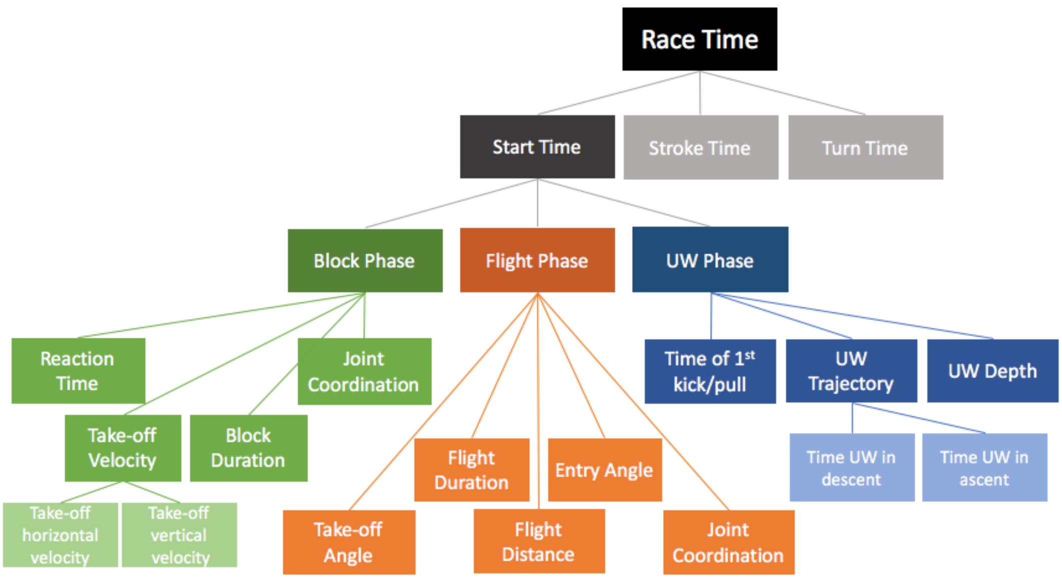

Figure 1 Key parameters of the start performance adapted from findings from Tor et al. (2015) and Vantorre, Seifert, Fernandes, Vilas-Boas, & Chollet, (2010a).

Using the track start (similar to the kick start), there is conflicting evidence if there is greater benefit of the front or rear weighted technique. When awaiting the start signal, swimmers hold a preparatory position with the centre of mass over the front or back foot, which alter joint angular displacement. Vilas-Boas, Cruz, Souza, Conceição, & Carvalho (2000) suggested different track starts have no significant impact on start performance. However, Welcher, Hinrichs, & George (2008) observed significantly greater horizontal velocity, in the rear-weighted start (3.99 m/s) than the front-weighted start (3.87 m/s).

There are distinct differences between the breaststroke and frontcrawl underwater phases. In a kinematical analysis of the breaststroke start, shorter start time was associated with a longer underwater phase, prominent in the initial glide after entry (Seifert, Vantorre, & Chollet, 2007). This finding should be applied with caution, one international swimmer was compared to ten national level swimmers: reducing reliability due to the unmatched samples. Block and flight phase durations were comparable to previous literature, suggesting no significant differences between the breaststroke and frontcrawl block and flight durations. The task goal in both strokes is to maintain velocity to carry into full stroke, and the swimmer decides when to initiate the underwater action (after glide) (Lyttle, Blanksby, Elliott, & Lloyd, 2000). A key difference between strokes is technique used post the initial glide: during the breaststroke underwater the first action post glide is a single arm pull before a breaststroke kick, however in frontcrawl, arms remain in a streamline position until breaking the water surface (Appendix 1.1). Another difference between the breaststroke and frontcrawl start is the plane of motion of the kick. The breaststroke kick uses large knee and hip adduction (Wanivenhaus, Fox, Chaudhury, & Rodeo, 2012). In frontcrawl the kicking action is predominantly flexion and extension at the hip, knee and ankle in the sagittal plane.

Tor et al. (2015) used a single repetition per participant when identifying key parameters of the start, similar to the practice of applied biomechanist's identifying normative data. Biomechanist's overlooked movement variability, assuming skilled athletes reproduced identical movement patterns in every repetition (Bartlett, Wheat, & Robins, 2007), hence minimal repetitions for averages and normative data. Once considered noise or "error", intra-individual differences in movement patterns were first considered important by Morriss, Bartlett, & Fowler (1997) investigating the javelin throw. Release speed was considered the main contributor to the javelin throw performance, but it was noted participants used different methods to generate release speed. Morriss, Bartlett, & Fowler (1997) recommended individual differences should be considered when coaching athletes and not always reject differences as performance error. This supports the dynamic systems theory; that views the body as a complex network of sub-systems (respiratory, circulatory, nervous, skeletomuscular and perceptual) co-dependent in generating movement patterns (Glazier, Davids, & Bartlett, 2003). Movement variability reflects performances generated by different organisation of these sub-systems. Consequently, movement variability is key to understanding sporting performance as flexibility of the body's sub-systems allows adaption to constraints of each performance (Bartlett, Wheat, & Robins, 2007). This is supported by recommendations to encourage swimmers to experience variation in start technique training (Formicola & Rainoldi, 2014) alluding to the benefit of coping with different potential constraints during performance.

Sanders (2007) used biological movement variability to compare hip, knee and ankle angular kinematics and coordination during the flutter kick. Sanders (2007) reported on average, skilled swimmers had less biological variation than learner swimmers in hip and knee actions (hip: skilled = 2.3%, learners = 7.0 – 19.6%; knee: skilled = 2.8%, learners = 3.5 – 14.2%). Greater variation in the joint kinematics of learner swimmers was reported as a performance error. Sanders (2007) suggested teachers should encourage learners to use specific joint ranges to reduce biological noise, contradicting dynamic systems theory. There are several issues with this study: firstly, the independent samples are unmatched (skilled swimmers average age: 28.9 years old and learner swimmers aged 9-11), questioning comparability between groups. Secondly, the level of competitive swimming experience was unspecified, so findings cannot be generalised to a particular level of swimmers. Additionally, the ‘flutter kick’ technique is not a full swimming stroke as there is no arm action. This may affect the kicking technique, therefore, findings should only be applied to the flutter kick without the use of arms, or comparing variability of learner and skilled swimmers.

Comparing movement variability in the grab start of elite and trained swimmers, Vantorre et al. (2010a) observed low inter-trial variability but high inter-subject variability (Table 1). These results suggest elite and trained swimmers use distinct motor patterns to perform the grab start.

Table 1 Intra-class correlations for start parameters (Vantorre et al., 2010)*. ICC: <0.4 – poor; 0.4-0.7 – fair; 0.7-0.9 – good; >0.9 - excellent*

	Elite	Trained
Block Phase	0.693	0.527
Flight Phase	0.925	0.899
Entry Phase	0.448	0.715
Glide Phase	0.776	0.732
Leg Kicking Phase	0.976	0.958
Swimming Phase	0.98	0.951
Aerial Phase	0.695	0.638
Underwater Phase	0.986	0.969
Impulse Horizontal Axis	0.846	0.957
Impulse Vertical Axis	0.587	0.808
Impulse Medio-lateral Axis	0.773	0.029

Vantorre et al. (2010a) proposed different task constraints for elite and trained swimmers to explain differing start effectiveness. Task constraint of elite swimmers included: compromising short block time and large impulse, and using a streamline position to conserve energy and delay full stroke. Task constraints of trained swimmers include managing the transition between phases and avoid losing too much time on the start. Whilst task constraints could differ between elite and trained swimmers, it is not conclusive to explain high inter-subject differences, as task constraints were not measured or quantified. Another limitation is that participants performed just three trials. Whilst this reduces fatigue affecting variability (Cortes, Onate, & Morrison, 2014), three trials may be too small to accurately identify variability. Bradshaw et al. (2007) proposed for high-velocity tasks, such as sprinting, participants should perform a similar number of repetitions common in training or competition, with adequate rest between attempts. Investigating 400 m coordination variability, Schnitzler, Seifert, & Chollet (2009) used data from all eight lengths in the variability calculations. This research investigated the grab start prior to the new block configuration. The additional kick plate (Figure 2), modified the start, developing a more efficient technique (kick start) that has a significantly greater horizontal take-off velocity and horizontal force (Honda, Sinclair, Mason, & Pease, 2010) than other start techniques. Consequently, investigation of the grab start's movement variability is outdated. Investigating movement variability using the kick or track start would be most relevant to competitive swimming.

Figure 2 OMEGA OSB11 Start Block with the 30° kick plate.

Seifert, Chollet, & Rouard (2007) investigated swimming constraints (Table 2) on arm coordination. Newell's (1986), theory of constraints proposes that to perform an action the individual has to adapt to task, environmental and organismic constraints (Newell & Liu, 2001).

Table 2 Swimming constraints investigated by (Seifert, Chollet, et al., 2007)

Constraint		
Task	Task goal	*(7 race paces over 25-m; self-selected)*
	Instructions given	
Environmental	Velocity Stroke Rate Stroke Length	*(Parameters required to generate propulsive force to overcome forward resistance created by aquatic environment)*
Organismic	Gender	
	Expertise	*(elite/mid-level swimmers)*
	Anthropometrics	*(height/stroke length ratio; arm span/stroke length ratio)*

According to dynamic system theorists, movement variability occurs when adapting to different constraints to consistently produce the best performance. Seifert et al. (2007) used the index of coordination (IdC) (Chollet, Chalies, & Chatard, 2000) to quantify arm coordination strategy (Table 3). All swimmers altered coordination strategy with race pace. Organismic constraints (gender and expertise) particulaly affected IdC. Elite women and mid-level men maintained catch up IdC when pace increased, whilst elite men adopted superposition IdC because they achieved faster velocity, overcoming greater forward resistance. Seifert et al. (2007) concluded task, organismic and environmental constraints influenced change in coordination strategy, and the catch up strategy is adaption to constraints, rather than performance error.

Table 3 Description of IdC strategies proposed by Chollet, Chalies, & Chatard (2000).

Index of Coordination Strategy	Description
Opposition	One arm pull phase begins as opposite arm push phase finishes. IdC = 0%.
Catch Up	There is a lag time between the propulsive phases of each arm. IdC < 0%.
Superposition	There is an overlap of each arms propulsive phase. IdC > 0%.

In the sprint start, biological variation is beneficial to performance, playing a vital role in function and execution of the action (Bradshaw et al., 2007); greater biological variability in coordination strategies (ankle rotation) was associated with decreased 10 m time. Additionally, greater joint coordination variability could play a vital role in reducing injury risk, by varying how the performance is produced prevents overuse of the same tissues (Bradshaw et al., 2007). These findings could be similar to the swimming start.

There is currently no movement variability research of the track or kick start. Seifert et al. (2010) identified four different flight techniques used with the grab start, but found no significant time to 15 m differences. This suggests technique used by the swimmer does not affect the task outcome (time to 15 m) (Bideault, Herault, & Seifert, 2013; Bradshaw et al., 2009; Button, MacLeod, Sanders, & Coleman, 2003). Similar to Vantorre et al. (2010), with small sample sizes in the four flight phase groups (n=1 to 5) and only three trials performed by each participant, findings are not reliable.

Constraints theory has been addressed in swimming research (Seifert, Chollet, et al., 2007; Vantorre et al., 2010), with variance in performance parameters a consequence of adaption to constraints rather than a performance error. Of the breaststroke and frontcrawl starts, the task constraint (stroke performed) changes the underwater technique, but block and flight techniques are consistent. It is not known if this task constraint affects the block and flight phase, or if movement variability is related to the task constraint. In the few studies reporting coefficient of variation (CV%) in swimming (Seifert et al., 2010; Vantorre et al., 2010), biological variation is not identified. A limitation of CV% is that technical error (for example error in the digitisation process) is not identified. To specifically measure biological movement variability (biological coefficient of variation; BCV%), extracting estimates of technical error (standard error of mean; SEM%) from the CV% is considered most appropriate (Bradshaw et al., 2007). When coefficient of variation can inflate biological variation by up to 72% (Bradshaw et al., 2007), it is vital BCV% should be used when investigating movement variability.

The aim of this research is to quantify movement variability in the breaststroke and front crawl starts of skilled swimmers. The research hypotheses are i) biological variation in breaststroke and frontcrawl start parameters will be significantly different; ii) greater biological variability will be observed in the joint kinematics during the block, flight and underwater phases than in task outcome (time to 15 m) for both strokes. This will be quantified with a full body two dimensional video analysis.

Chapter 2

8. Method

8.1. Participants

Ethical approval was granted by the University of Chester Faculty of Science and Engineering Research Ethics Committee (25/04/2016; reference: 043/16/JS/SES, Appendix 2). Four male and six female swimmers (Table 4) of club and county standard were recruited using convenience sampling (University of Chester SC, Thetford Dolphins SC) who had at least five years competitive swimming experience. As only one-tailed hypotheses were used, based on a sample size of 10, a significance level of 0.05 (α), power (1-β) of 0.8, a moderate effect size of 0.75 was predicted using Cohen's classification scheme (Cohen, 1988). As previous research observed a range of effect size (small – large), most commonly moderate to large (McCabe, Psycharakis, & Sanders, 2011; Tor, Pease, & Ball, 2014), a moderate – large effect size was considered sufficient.

Table 4 Participant characteristics (mean ± standard deviation)

Gender	n	Age (years)	Mass (kg)	Height (cm)	Competitive Experience (years)
Male	4	19.8 ± 0.8	67.1 ± 3.1	176.8 ± 2.05	8.8 ± 2.3
Female	6	18.7 ± 0.7	72.3 ± 2.8	160.7 ± 6.7	8.5 ± 1.8
All	10	19.2 ± 1.2	70.3 ± 3.9	167.1 ± 9.5	8.6 ± 2.0

8.2. Design

A single group, repeated measures experimental design was used. The independent variable measured was the swimming stroke (breaststroke and frontcrawl). Dependent variables were the temporal-spatial parameters of all start phases (Appendix 1.2) and sagittal plane hip, knee and ankle angular displacement, velocity, and acceleration for above water phases (Appendix 1.2).

8.3. Procedures

Data collection took place at the University of Chester swimming pool and Breckland Leisure Centre in a one-hour data collection session. Figure 3, demonstrates camera details and poolside setup. A study number was allocated to participants for data anonymity. Participants were given a Participant Information Sheet providing information on the study and their right to withdraw from the study at any point. Participants were instructed to email the researcher if they wanted a research summary post project completion.

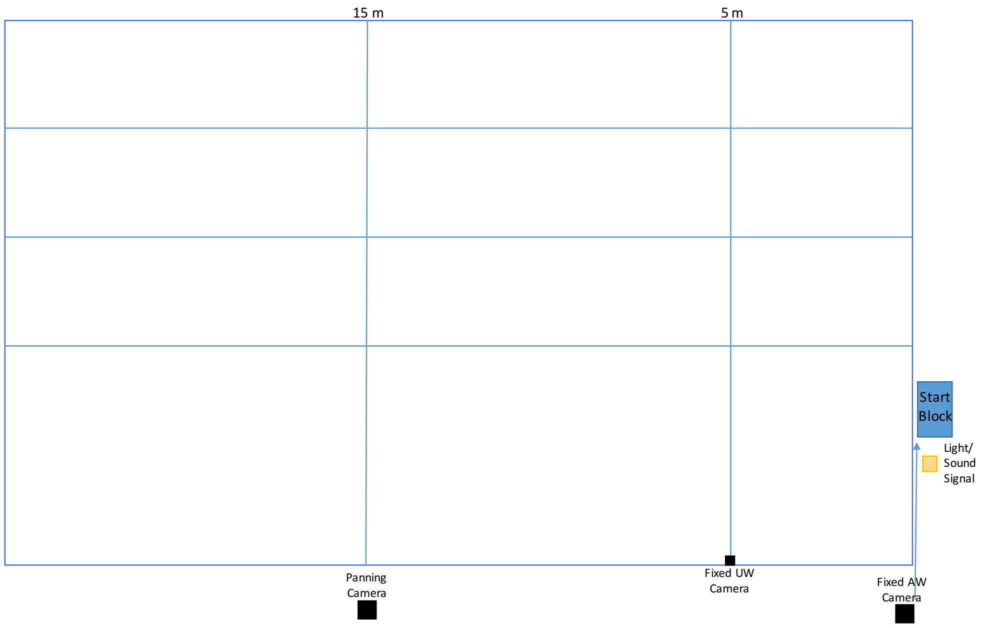

Figure 3 Two dimensional video data of the block and flight phase captured with a fixed above water (AW) camera (Fujifilm FinePix XP200; frame rate: 120 Hz; shutter speed: camera auto-settings) A fixed underwater (UW) camera (GoPro Hero4 Silver; frame rate: 50 Hz; shutter speed: camera underwater default settings) captured UW phase. An above water camera (Fujifilm FinePix XP80; frame rate: 60 Hz; shutter speed: camera auto-settings) captured 0 – 15 m to measure start time within 0.016 s accuracy.

Participants completed a self-selected warm up of 400-800m at a common training warm up pace (Reiwald, 2015). Post warm-up, the swimmer was marked with kinesiology tape on anatomical landmarks (Figure 4) used in post-capture digitisation process. A custom-made inverted T-shaped frame was used to calibrate the static above water camera, and a submerged rectangular calibration frame was used to calibrate the static underwater camera, both positioned central in the camera's field of view.

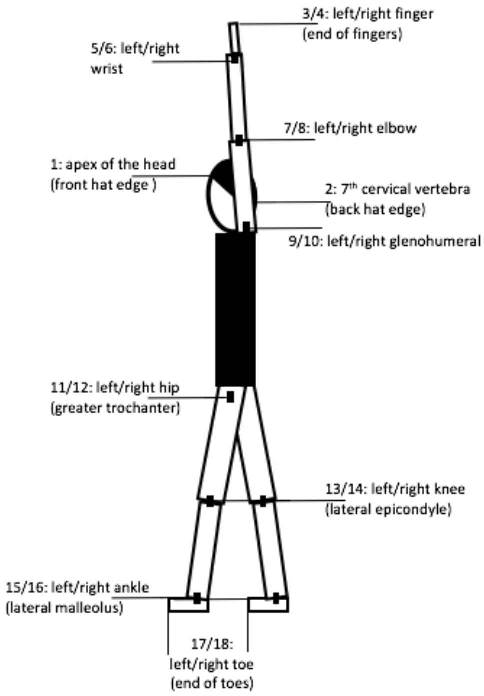

Figure 4 18 point marker model used in digitization process. Markers attached to swimmer during data capture: 5/6 [single marker], 7/8 [single marker] 9/10 [single marker]; 11/12[single marker], and 13:16. Landmarks identified post capture without markers: 1:4, 17 and 18.

A synchronized sound and light system was used to signal the start of the trial. Each participant performed ten 25-m breaststroke and ten 25-m frontcrawl sprints (order randomised and counterbalanced) using the track start technique with a two minute rest period between sprints (Toubekis, Douda, & Tokmakidis, 2005).

To replicate the first length of a 50 m sprint (short course) and to alleviate potential inconsistent deceleration within the recorded 15 m, participants sprinted 25-m (Vantorre et al., 2010). Participants then completed a 10 minute self-selected cool down, at 55-60% of maximum velocity (Stager, Stickford, & Grand, 2015).

Data analysis

Quintic software (Quintic Consultancy Ltd., Coventry, UK) was used to manually digitise each above-water video using an 18-point full body model (Appendix 1.3) to provide position and temporal data for each segment and centre of mass (COM) location. Joint kinematics were calculated for the lower body in the sagittal plane about the mediolateral axis, throughout the block and flight phases. Above water data was digitised at 60 Hz and smoothed using a second-order low pass Butterworth filter with cut-off frequencies ranging from 9-32 Hz. Underwater data was sampled at 50 Hz, and smoothed using a second-order low pass Butterworth filter with cut-off frequencies ranging from 6 – 13 Hz. Cut-off frequencies were selected on a trial by trial basis, using optimum values calculated using residual analysis (Willmott & Dapena, 2012), to reduce noise and processed data was exported into excel. After a visual inspection of the data collected, angular data was disregarded for two participants (n=8) and for three participants’ underwater data (n=7), as they were not deemed good enough to analyse.

Participants mean (X) and standard deviation (SD) was used to estimate technical error (SEM% = [(SD/√*n*)/X] x 100, where *n* is the number of trials), and coefficients of variation (CV% = SD/X x 100) to calculate biological coefficients of variation (BCV% = CV% - SEM%) of the dependent variables for each stroke (Bradshaw et al., 2007). BCV% values of lower limb angular kinematics at block take-off and water entry were used to quantify joint coordination variation (Bradshaw et al., 2007). Leading leg hip, knee and ankle angular displacement and velocity of the breaststroke and frontcrawl starts were compared. Additionally, centre of mass angle at both take-off and entry have previously been investigated in start performance (Tor et al., 2015) and therefore were investigated. Qualitative investigation of the underwater phase included hip trajectory comparison of the underwater and frontcrawl entry to the underwater phase in the cameras field of view. Due to data capture on differing days, only intra-subject comparisons were made as inter-subject set up could make comparisons invalid.

8.4. Statistical Analysis

Statistical analyses were performed using SPSS 22.0 (IBM Corporation, New York, USA). A Shapiro-Wilk statistic found the majority of parameters to be normally distributed ($p>0.05$), so normal distribution was assumed (Appendix 5.2). A series of paired t-tests compared mean CV%, SEM% and BCV% to identify significant differences in variability between the breaststroke and frontcrawl start for all dependent variables. Additional paired t-tests compared CV% to BCV% of each parameter specific to stroke. Bonferroni corrections for multiple comparisons were performed to reduce the risk of a type I error ($a = 0.05/18 = 0.003$). Effect sizes were calculated, using Cohen's criteria (1988), to identify if a small (0.2), medium (0.5) or large (0.8) to quantify the meaningfulness of the differences.

Chapter 3

9. Results

Time to 15 m was significantly faster (t = 11.17; d.f. 9; $p<0.01$) in the frontcrawl start than the breaststroke start (Table 5) with a large effect size observed (d = 3.51). Overall, no significant difference between breaststroke and frontcrawl biological variation in start parameters (Table 6 – 8) was observed, therefore research hypotheses (1) should be rejected. There was less biological variation in both breaststroke and frontcrawl time to 15 m (Table 5), than other start parameters (2.01 % - 9.55 %), therefore research hypothesis (2) can be accepted.

Table 5 Time to 15 m mean, coefficient of variation (CV) and biological coefficient of variation (BCV) for breaststroke (BS) and frontcrawl (FC).

	Time to 15 m	
	BS	FC
Mean (s)	11.31 ± 0.85	9.04 ± 0.46
CV (%)	2.01 ± 0.55	1.76 ± 0.84
BCV (%)	1.38 ± 0.38	1.20 ± 0.58

9.1. Linear Kinematics

Although frontcrawl block time was 0.06 s faster, it was not significant. Similarly, the breaststroke flight time was not significantly faster than the frontcrawl flight time. The duration of the underwater phase was significantly longer for breaststroke than frontcrawl (6.31 s ± 0.98 s: 4.86 s ± 0.72 s) (t = 7.08; d.f. 9; $p<0.01$), reflecting the differing underwater techniques utilized. In accordance with FINA rules, the swimmer will perform an arm pull, a single butterfly kick and a breaststroke kick during the breaststroke underwater phase. In the frontcrawl underwater phase the swimmer is only permitted to use the frontcrawl kicking action, or the butterfly “flutter” kick prior to surfacing. Breaststroke stroke time was significantly longer than frontcrawl ($t = 4.68$; d.f. 9; $p<0.01$) (Table 6); large effect sizes were observed for underwater duration and stroke time.

Breaststroke block time had 3.72 % variation, of which 66 % was biological. In frontcrawl, there was less variability (2.87 %) in block time but a greater proportion (70 %) was considered biological. Although a greater proportion of variation observed was biological in frontcrawl block time, absolute biological variation was slightly less than breaststroke (2.01 % and 2.49 %) (Table 6). There was 1.21 % greater movement variation in breaststroke flight time. Only 29 % of this variation (0.35 %) was biological, which was not a meaningful difference ($d = 0.18$). TEM was recorded in breaststroke and frontcrawl take-off velocity, but there was 4.41 % greater biological variability in breaststroke take-off velocity (Table 6). No significant differences were observed between all temporal-spatial parameters comparing variability measured using CV% or BCV%.

Table 6 Linear Kinematics with Coefficient of Variation (CV%) and Biological Coefficient of Variation (BCV%) (Mean ± SD) for breastsroke (BS) and frontcrawl (FC).

	Mean			CV (%)			BCV (%)		
	BS	FC	Cohen's d	BS	FC	Cohen's d	BS	FC	Cohen's d
Block Time (s)	0.88 ± 0.05	0.82 ± 0.20	0.33	3.72 ± 1.97	2.87 ± 1.42	0.59	2.49 ± 1.33	2.01 ± 0.93	0.56
Flight Time (s)	0.27 ± 0.07	0.33 ± 0.19	0.32	6.91 ± 2.71	5.70 ± 1.36	0.50	4.72 ± 1.85	4.37 ± 1.82	0.18
Flight Distance (m)	2.21 ± 0.28	2.21 ± 0.28	0.09	2.48 ± 0.96	2.12 ± 1.06	0.35	1.69 ± 0.66	1.45 ± 0.73	0.35
Underwater Time (s)	6.31 ± 0.98	4.86 ± 0.72	2.24 *	7.31 ± 1.83	6.50 ± 2.49	0.44	5.17 ± 1.31	4.45 ± 1.70	0.52
Stroke Time (s)	4.88 ± 1.12	4.17 ± 0.91	1.48 *	7.48 ± 3.64	8.62 ± 4.30	0.54	5.12 ± 2.49	5.90 ± 2.94	0.53
Take-off Horizontal Velocity (m/s)	2.81 ± 0.38	2.91 ± 0.33	0.68	13.84 ± 13.79	7.49 ± 4.40	0.57	9.46 ± 9.43	5.13 ± 3.00	0.57
Take-off Resultant Velocity (m/s)	2.82 ± 0.37	2.93 ± 0.33	0.71	13.97 ± 13.63	7.52 ± 4.39	0.59	9.55 ± 9.32	5.14 ± 3.01	0.58
Average Flight Velocity (m/s)	3.19 ± 0.41	3.27 ± 0.33	0.40	10.90 ± 13.01	5.34 ± 1.57	0.43	7.45 ± 8.90	3.65 ± 1.08	0.43

* $p < 0.01$

9.2. Angular Kinematics

Tables 7 and 8 summarizes breaststroke and frontcrawl mean values and movement variation during the block phase and at entry of angular kinematic parameters. Although not significant, a greater take-off angle was observed in the breaststroke start (51.70° ± 7.73°) than the frontcrawl start (50.72° ± 5.80°), with 1.89 % more biological variation in the breaststroke start. The COM angle entry was marginally greater in the breaststroke start (269.80° ± 8.28°) than the frontcrawl start (268.72° ± 8.28°). This greater entry angle could contribute to the greater maximum depth achieved underwater in breaststroke (Figure 5). No significant differences were observed between breaststroke and frontcrawl for any angular kinematic parameters. Biological coefficient of variation of the angular kinematic measures were, overall marginally greater than linear kinematic measures for both starts, with typical BCV's of 1.45 – 9.55 % (Table 6) and 1.17 – 8.07 % (Table 7) respectively. Biological movement variation of lead hip, knee and ankle angular velocities at take-off with BCV's of 13.48 – 335.96 % (Table 8), were much greater than angular displacement.

Table 7 Angular Displacement of Lead Hip, Knee and Ankle at Take-off (TO) (Mean ± SD) for breaststroke (BS) and frontcrawl (FC).

	Angular Displacement								
	Mean (◦)			CV (%)			BCV (%)		
	BS	FC	Cohen's d	BS	FC	Cohen's d	BS	FC	Cohen's d
COM at TO	51.70 ± 7.73	50.72 ± 5.80	0.30	11.80 ± 6.48	9.03 ± 2.97	0.40	8.07 ± 4.43	6.18 ± 2.03	0.40
TO Lead Hip	282.34 ± 9.01	282.46 ± 7.82	0.03	4.00 ± 1.81	4.00 ± 1.85	0.08	2.73 ± 1.23	2.74 ± 1.26	0.09
TO Lead Knee	110.91 ± 12.09	109.10 ± 12.58	0.58	7.45 ± 3.49	7.67 ± 3.81	0.54	5.09 ± 2.38	5.24 ± 2.61	0.53
TO Lead Ankle	267.63 ± 7.43	268.83 ± 7.69	0.18	2.08 ± 0.76	2.07 ± 0.74	0.26	1.42 ± 0.52	1.42 ± 0.52	0.21
COM at Entry	269.83 ± 8.28	268.72 ± 7.75	0.71	1.78 ± 0.97	1.71 ± 0.62	0.07	1.22 ± 0.66	1.17 ± 0.43	0.06

Table 8 Angular Velocity of Lead Hip, Knee and Ankle at Take-off (TO) (Mean ± SD) for breaststroke (BS) and frontcrawl (FC).

	Angular Velocity								
	Mean (◦/s)			CV (%)			BCV (%)		
	BS	FC	Cohen's d	BS	FC	Cohen's d	BS	FC	Cohen's d
TO Lead Hip	-586.98 ± 190.27	-604.58 ± 194.56	0.38	21.00 ± 14.32	19.71 ± 11.67	0.41	14.36 ± 9.79	13.48 ± 7.98	0.41
TO Lead Knee	355.35 ± 172.25	365.91 ± 144.91	0.58	76.79 ± 61.86	64.90 ± 43.28	0.45	52.51 ± 42.30	44.37 ± 29.59	0.45
TO Lead Ankle	-151.46 ± 153.15	-102.35 ± 167.79	0.18	491.34 ± 541.29	125.62 ± 266.43	0.65	335.96 ± 370.12	85.90 ± 182.18	0.65

9.3. Underwater Analysis

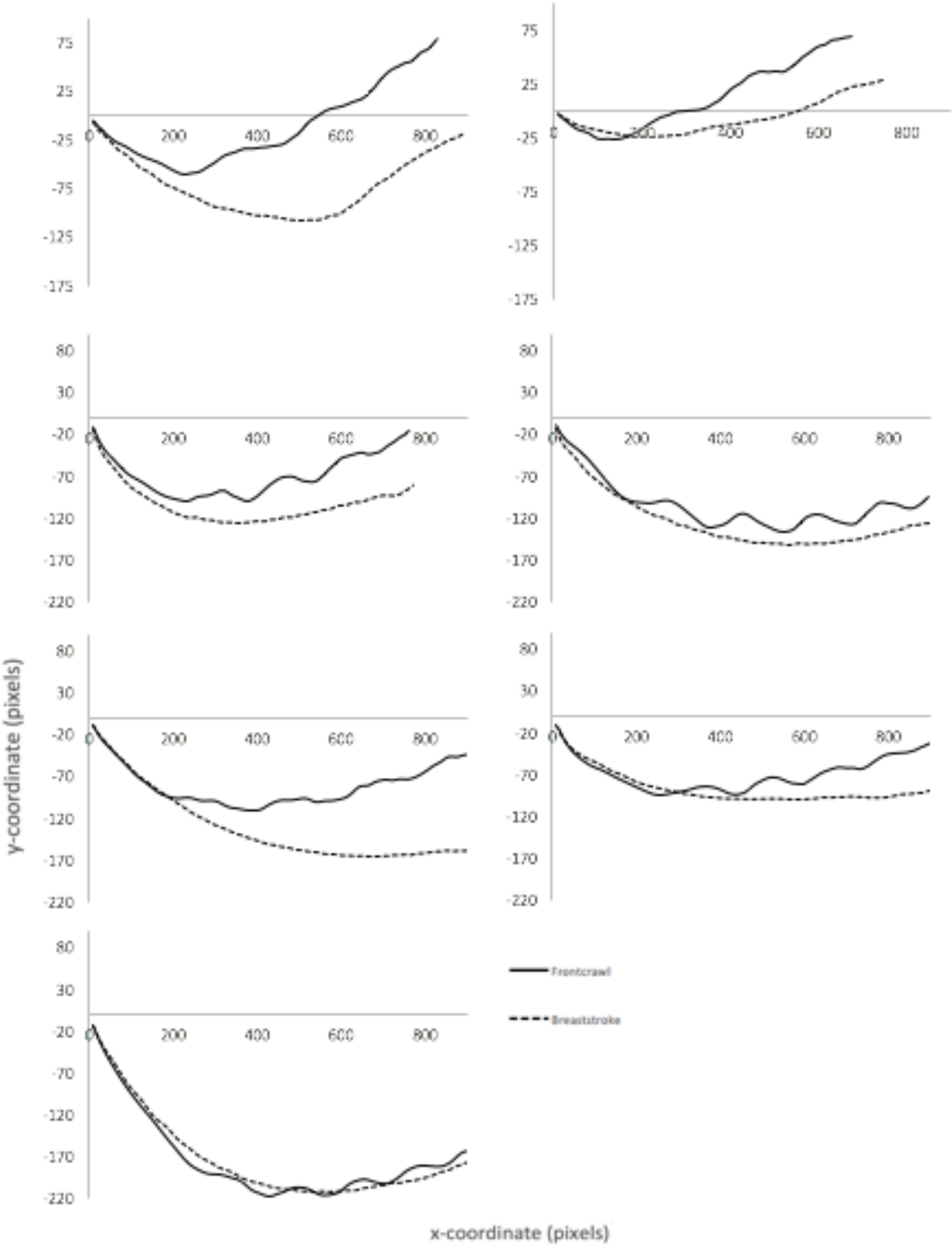

Figure 5 Mean underwater trajectory of frontcrawl and breaststroke start recorded from hip enrty.

Figure 5 displays each participant's mean entry trajectory to the underwater phase of the breaststroke and frontcrawl starts. Four participants reached a greater maximum depth during the breaststroke underwater phase, with the remaining three swimmers reaching comparable maximum depth in both strokes. In the frontcrawl start, different techniques are visible by more distinct hip undulations, reflecting the flutter kicking action of the frontcrawl underwater phase (in accordance with FINA rules). In breaststroke, underwater technique begins with a hand pull to hip, prior to a breaststroke kick which means swimmers typically use a longer glide phase. The different techniques result in a further distance travelled underwater during the breaststroke underwater phase, reflected by six of seven swimmers remaining at a greater depth within the captured field of view at the last point of recording. Greater depth could be related to further distance travelled for a longer duration. This is supported by the significantly greater breaststroke underwater duration (Table 6).

One participant (Figure 5) had similar maximum depths and remained at similar depths at the last point of recording in both breaststroke and frontcrawl. Despite this, the mean underwater duration was longer during the breaststroke (6.19 s) than frontcrawl start (5.24 s). An unrecorded part of the breaststroke underwater could have prolonged the underwater phase, highlighting inter-subject variation in underwater technique between swimmers.

Chapter 4

10. Discussion

This research aimed to quantify biological movement variability in the breaststroke and frontcrawl starts and to compare variability between the two strokes. Additionally, variability between measured parameters were observed. Whilst there was no significant difference between biological variation in start parameters of breaststroke and frontcrawl, task outcome (time to 15 m) presented the least biological variation of all start parameters measured.

10.1. Breaststroke versus Frontcrawl

Dynamic systems theorist propose movement variation is not a performance error or “noise” (Morriss, Bartlett, & Fowler, 1997). Conversely, it reflects adaption to performance constraints (Bartlett et al., 2007). The effect of constraints on swimming performance observed in different distance events relate to differing stroke coordination patterns, and one stroke coordination pattern thought as an error may be due to event distance (Seifert, Chollet, et al., 2007). Furthermore, Vantorre et al. (2010) suggested different constraints specific to swimmer ability may alter the performance of the grab start between subgroups. This current study is the first to compare biological variability of the swimming start when changing the task constraint: stroke performed.

In the present study, altering task constraint produced significantly different mean underwater and stroke time, as well as the task outcome (time to 15 m).

Where differences occurred in the start, there was no significant variation between breaststroke and frontcrawl start parameters. This suggests stroke swam does not affect the variation in components of start.

Tor, Pease, & Ball (2015) identified the key parameters in start performance, identifying take-off horizontal velocity as the most critical above water parameter to start performance. In this research an average of 4.36 % greater biological variation was observed in the breaststroke start (Table 6). Whilst this is not significantly greater than frontcrawl, greater variability could reflect swimmers adapting to other start performance constraints.

10.2 Performance Outcome Variability

Greater variability was expected in the start parameters investigated than in start performance (time to 15 m). Although not statistically tested, time to 15 m (task outcome) had less biological variation than other variables in both strokes. Biological variation in phase durations (1.45 – 9.55 %) and angular displacements (1.17 – 8.07 %) were both greater than task outcome, but greatest biological variation was observed in angular velocity of lead leg: hip, knee and ankle at take-off (Table 8). This supports dynamic systems theory, variation in the parameters generating the start is not necessarily a limitation of performance. It further supports the theory that variation within the action prevents overloading of particular joints at key points, such as take-off, that could relate to overuse injuries. Although, no significant difference in variation was observed when stroke (task constraint) was changed, the variation may reflect adaption to other constraints not controlled for within this study, such as fatigue (Bradshaw et al., 2007).

Qualitative analysis of the underwater entry phase clearly demonstrates differences between the two strokes – such as maximum depth (Figure 5). Naemi, Easson, & Sanders, 2010; Tor et al. (2015) suggested the underwater phase is the most important start phase, with factors such as maximum depth highlighted as crucial factors. It has been demonstrated, that although analysis is limited, maximum underwater depth differs between strokes, with varying trajectories reflecting differing underwater technique. This is evident between participants as well as between strokes (Figure 5). From the qualitative analysis conducted, an in depth quantitative variability analysis of the underwater phase would be beneficial for identifying variability between strokes and the impact this has on start performance.

Biological variation (BCV%) was identified by estimating technical error (SEM%) within coefficient of variation (CV%). Findings suggest that coefficient of variation was significantly greater than biological variation. This has significant implications for interpreting past research and future movement variation investigation. Whilst coefficient of variation is a measure of movement variability, it is inclusive of variation related to technical error and therefore is not specific to the performance biological variation. This supports Bradshaw et al. (2007), who reported biological variation was inflated by 72% when technical error was not accounted for, and this research further supports that caution should be taken when comparing variability between studies when biological variation has not been identified.

10.3. Main Strengths and Limitations

Previous research has investigated movement variability when using the grab start (Seifert et al., 2010; Vantorre et al., 2010). This research is the first to investigate movement variability when using the track start; with a specific focus on biological variation, by removing estimates of technical error. In this research, similar to findings by Bradshaw et al. (2007), using coefficient of variation overestimates movement variation purely from the individuals performance. Therefore, biological coefficient of variation is a more appropriate method when investigating movement variation (Bradshaw et al., 2007).

This research is also the first to investigate if any differences in movement variation occur when performing the track start for two different swimming strokes: breaststroke and frontcrawl. In swimming, task constraints (event distance) have significantly influenced variability in stroke coordination (Seifert, Chollet, et al., 2007), however, as this research has shown, although frontcrawl displayed slightly less variation in most start parameters, the differences in variation were not significant. This is beneficial for generalising research findings from the track start to other research which may have used an alternative swimming stroke, and could therefore be seen as a confounding variation, however this research has shown it would not be when investigating movement variability of the start.

There are limitations to data collection techniques used to conduct this results. Specifically, only qualitative data was captured for the underwater phase, considered the most important phase of the start (Tor et al., 2015). There are key elements to the breaststroke underwater that could not be identified in the capture area and biological variation of key parameters of the underwater phase could not be quantified. Key parameters such as time in descent, time in ascent and maximum depth are pertinent to the start, future studies should consider assessing biological variability of these parameters to identify the effect, if any, variation has on start performance and if there are differences between strokes.

Where no significant differences were identified in the above water parameters between strokes, the number of participants used could hold some explanations. Additionally, the limited sample population included male and female participants of varied ability (club to regional level), and whilst repeated measures design will have minimised the impact of this, not controlling these organismic constraints, previously identified to impact on swimming performance (Seifert, Chollet, et al., 2007), could hold explanation for insignificant findings.

The use of skin mounted joint markers introduced limitations. All kinematic data was collected from a single side; although this provided consistency and replicability between participants, consequently the lead leg during the block phase was not always the ipsilateral limb. When the contralateral limb was the lead leg, during the digitisation process, this results in obscuration of some joint markers. Whilst using joint markers improves validity of movement variation reported (Bartlett, Bussey, & Flyger, 2006), two dimensional data collection occasionally meant some joint marker locations were estimated.

Another limitation is the impact of attached marker to skin, introducing potential soft tissue artefacts, with further difficulties of ensure durability in water. A single researcher attached all markers, replaced lost markers between trials and digitised all data to provide some control, but this data collection method should be considered when interpreting data and in future studies. The use of three dimensional marker-less methods, such as Visual Hull techniques and / or computational fluid dynamics of the start would eradicate some data collection issues identified with two dimensional kinematic analyses. This would also provide a more comprehensive analysis of joints in all planes of motion, particularly pertinent to lower limb adduction in the breaststroke kick during the underwater phase.

Specific to the level of swimmer in this research, the track start technique was analysed. Whilst this is important progress from previous grab start analysis (Seifert et al., 2010; Vantorre et al., 2010), these findings are not transferable to elite swimmers using the kick start technique. Significant differences between kick and track start (Honda et al., 2010) may result in different movement variability in performance. To understand movement variability of the kick start, future studies should investigate biological variability of elite swimmers using the kick start.

10.4. Conclusion

In summary, when comparing biological movement variability of breaststroke and frontcrawl starts, there were no significant differences despite a significantly faster task outcome when performing the frontcrawl start. In general, variation in frontcrawl start parameters were lower than in breaststroke. The level of swimmers analysed could hold the explanation, as it is more common for club level swimmers to regularly perform frontcrawl and not specialise in breaststroke swimming. The greater variation in breaststroke start parameters may reflect fatigue, and unfamiliarity of repeatedly performing maximum effort breaststroke starts. Greater biological variation was observed in all start parameters than in task outcome in both strokes. This supports the dynamic systems theory, as variation in performance generation does not impact overall start performance; it could reflect adaption to performance constraints and offers further support that variation is preventing repetitive overloading of the same soft tissue to replicate performance. Variation in how the swimming start is performed should not always be considered a performance error.

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12. Appendices

Appendix 1 – Additional information

Appendix 1.1. Track start phases

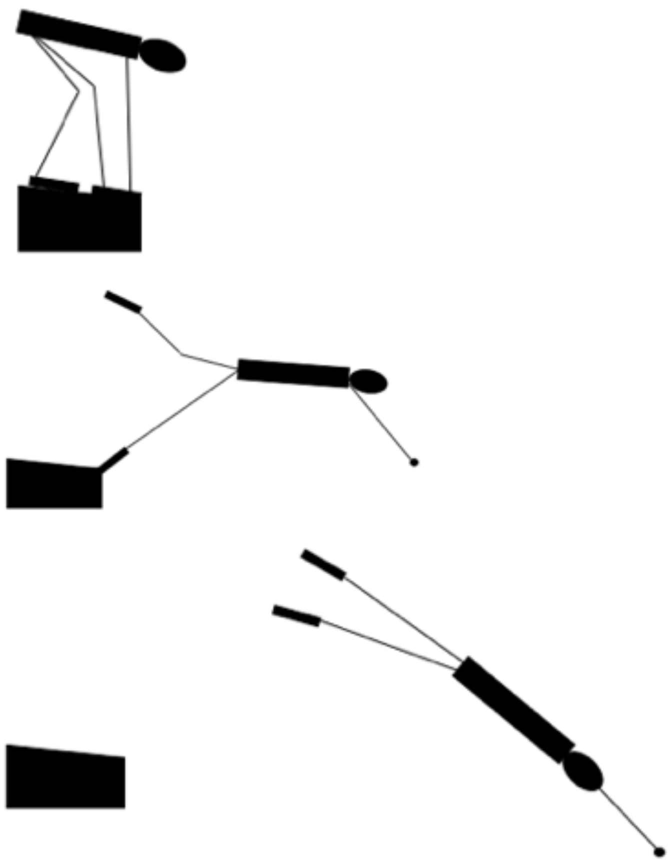
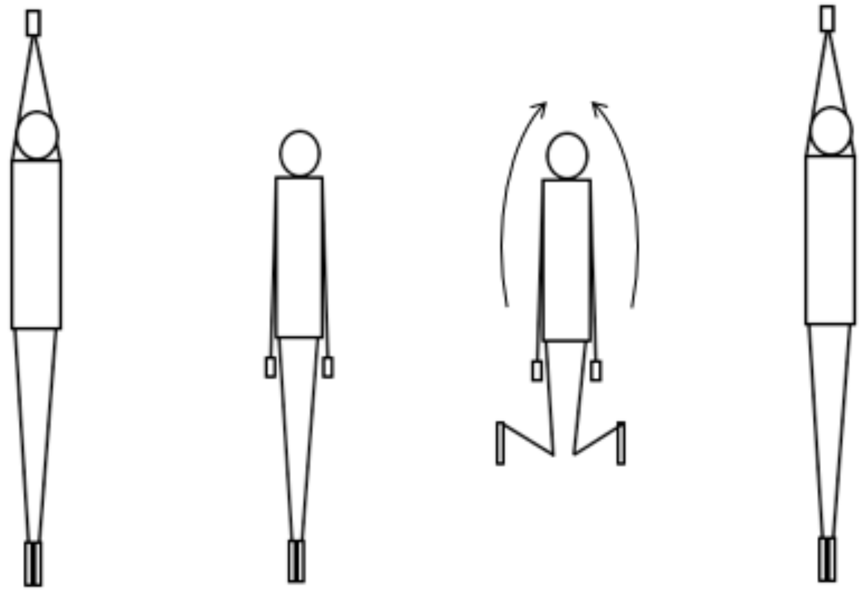


Figure 6 Block and flight phases of the track start: 1) Body position held at the "take your marks" signal; 2) Take-off, ending block phase and initiating flight phase; 3) End of fight phase as the apex of the end enters the water, beginning the underwater phase.



Swimmer enters water in streamlined position. F/C: butterfly kicks to the surface.	Br/S: After a glide, swimmer does one arm pull to the hips and a single butterfly kick .	Br/S: A single breaststroke kick and recovery arm phase back to the original glide position	Br/S: Swimmer remains in this streamlined position until reaching the surface.

Figure 7 Ariel view of the breaststroke (Br/S) and front crawl (F/C) underwater phase (Lyttle & Blanksby, 2015).

Appendix 1.2. Dependent variables

Table 9 Table defining each dependent variable to analyse for movement variation during the block and flight phases of for both the breaststroke and frontcrawl sprint starts (UW: underwater CoM: centre of mass)

Dependent Variable	**Definition**
Time to 15 m (s)	Time from start signal to when the apex of the head reaches 15 m
Time on block (s)	Time from start signal to when the feet leave the block
Entry distance (m)	Distance from the start wall to head entry
Flight duration (s)	Time from when the feet leave the block to when the apex of the head first enters the water
UW duration (s)	Time from when the apex of the head first enters the water to reaching 15 m
UW glide phase (s)	Time from head entering the water to first kick initiation
UW kick phase (s)	Time from first kick initiation (frontcrawl) or first arm pull (breaststroke) to breakout phase
UW phase distance (m)	Distance from head apex entering water to breaking water
Breakout distance	Distance from start wall to apex of head breakout (if 15 m is not reached)
Time of maximum depth (s)	Time from start signal
Horizontal distance of maximum depth (m)	Distance from start wall to point CoM reaches maximum depth
Time of first kick (s)	Time at which the first kick (frontcrawl) or pull (breaststroke) is initiated during UW
Take-off horizontal velocity (m/s)	The change in horizontal displacement when the swimmer is leaving the block
Take-off vertical velocity (m/s)	The change in vertical displacement when the swimmer is leaving the block
Average Flight velocity (m/s)	The change in horizontal displacement from the last point of contact with the block, to when the apex of the head enters the water
CoM take-off angle (°)	CoM angle at last point of block contact (relative to the horizontal and edge of block).
CoM entry angle (°)	CoM angle as apex of head enters the water (relative to the vertical and apex of the head).
Time UW in descent (s)	Duration from apex of the head entering the water, to CoM maximum depth
Time UW in ascent (s)	Duration from CoM maximum depth to apex of the head at breakout
UW average velocity (m/s)	Change in displacement from apex of the head entering the water to breakout

*Table 10 Breaststroke specific underwater (UW) dependent variables (*Riewald and Rodeo, 2015).

Breaststroke Specific UW Dependent Variable	**Definition**
Arm pull – push to hips (s)	From initial arm pull from streamline to pushing towards hips so are arms are fully extended by sides
Dolphin kick (s)	From when feet initiate a downbeat, to the completion of the upbeat kick symmetrically
Breaststroke kick (s)	Duration of one complete breaststroke kick
Arm recovery (s)	From arms flexing to bring back into the streamline position to breakout

Table 11 Lower limb joint couplings to be analysed for coordination variability using NoRMS method. All angles in the sagittal plane about the mediolateral axis.

Joint Coupling	**Definition**
Ankle – Knee	Ankle plantarflexion/dorsiflexion – Knee flexion/extension
Knee – Hip	Knee flexion/extension - Hip flexion/extension
Ankle - Hip	Ankle plantarflexion/dorsiflexion - Hip flexion/extension

Appendix 1.3. 18-point full body model

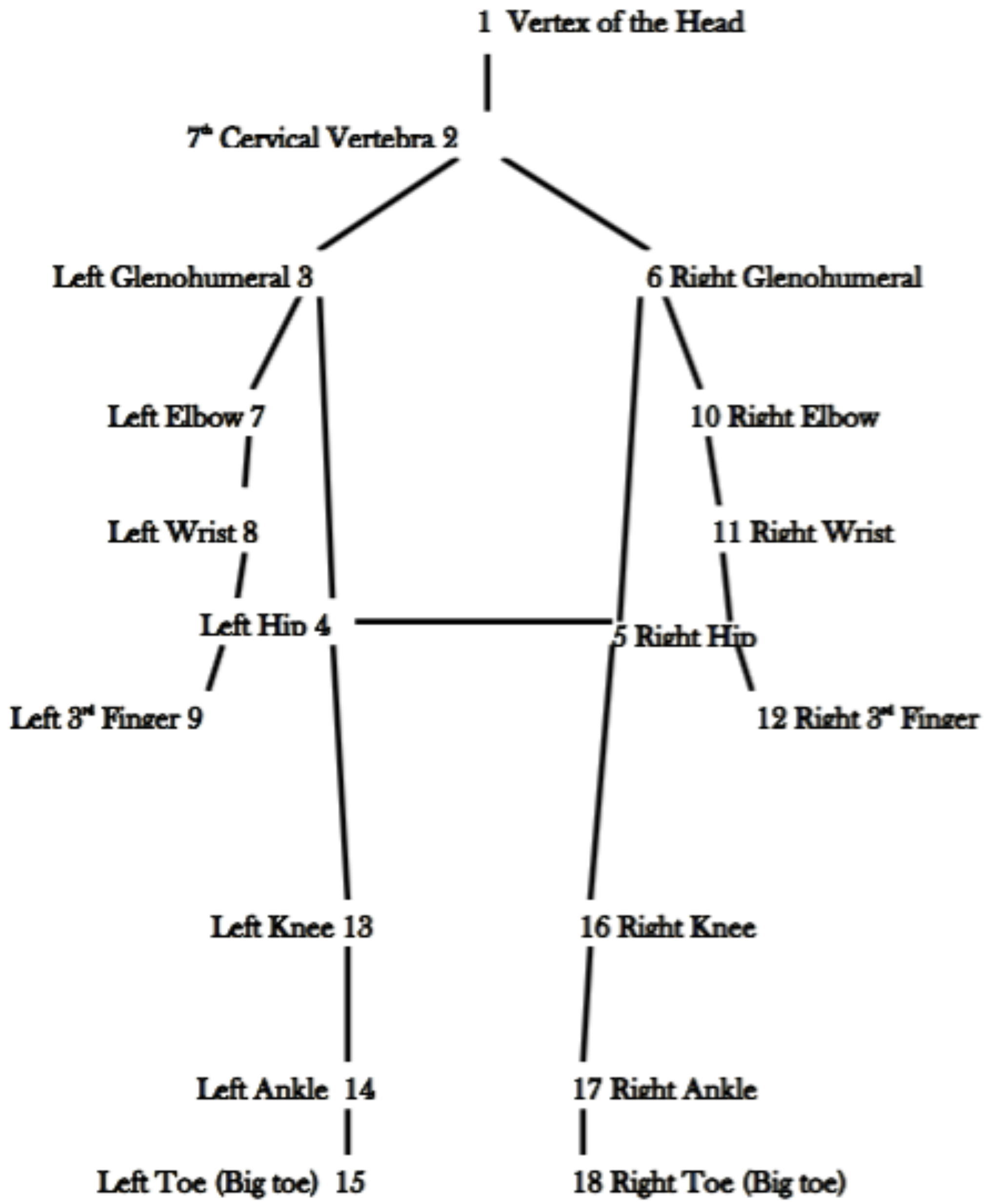


Figure 8 Quintic 18 point model, to be used for digitisation (Quintic Consultancy Ltd., Coventry, UK).

Appendix 2 – Ethical approval application

This can be found on the attached USB. It contains:

Appendix 2.1. Ethical application form

Appendix 2.2. Appendices for ethical approval

Appendix 2.3. Ethical approval confirmation letter

Appendix 2.4. Approval of research amendments

Appendix 3 – Participant details

Table 12 Participant information; group mean and SD; male and female mean and SD

Participant	M/F	DOB	Age	Mass	Height	Years' Experience	Training Hours Per week	Leg Forward
1	F	19/12/1996	19	77	171	10	8.5	L
2	M	04/08/1994	22	65.5	175	11	7	L
3	M	14/01/1996	20	69	177	11	7	L
4	F	26/06/1996	20	70	155	10	8	R
5	F	16/01/1998	18	71	169	8	10	R
6	F	05/02/1998	18	68.5	157	10	8.5	R
7	M	20/10/1996	19	71	175	7	4	L
8	F	21/07/1997	19	73.5	158	5	9	R
9	F	15/11/1997	18	74	154	8	4	L
10	M	28/07/1997	19	63	180	6	6	R
MEAN			19.20	70.25	167.10	8.60	7.20	
STD DEV			1.17	3.89	9.54	2.01	1.93	
Male		MEAN	20.0	67.1	176.8	8.8	6.0	
		STD DEV	1.2	3.1	2.05	2.3	1.2	
Female		MEAN	18.7	72.3	160.7	8.5	8.0	
		STD DEV	0.7	2.8	6.7	1.8	1.9	

Appendix 4 – Raw data

This can be found in a subfolder on the attached USB. It contain raw data for all participants.

Appendix 5 – Statistical analyses

This can be found on the attached USB. It contains:

Appendix 5.1. SPSS input and output files

Appendix 5.2. p values

Appendix 6 – Results files

This can be found on the attached USB. It contains:

Appendix 6.1. Raw exported data

Appendix 6.2. Results excel spread sheets